Hydrogen fuel- clean, plentiful and not ready

By SHIPPING AUSTRALIA

Pictured: a European feeder ship underway on a river. European inland river-ship operators are experimenting with hydrogen as a ship fuel. Photo credit: Vidara Nordli-Mathisen via Unsplash.

Hydrogen is potentially one of the best fuels around.

Kilogram for kilogram, hydrogen is the king of energy content with a whopping 2.6 times more energy content than the second-most energy rich fuel, methane. Hydrogen boasts of 142.2 megajoules of energy per kilogram, according to the Engineering Toolbox. Methane has an energy content of 54.0 MJ/kg, conventional diesel 45.8 MJ/kg and residual oil about 42.2 MJ/kg.

There's no shortage of hydrogen. About 50 million tonnes of hydrogen is produced each year, which is equivalent to about 150 million tonnes of ship's fuel, reports class society DNV GL. Hydrogen is produced through industrial processes, so production can in theory be ramped up as necessary.

It's also the cleanest combusting fuel any industrial civilization could hope to burn.

Although hydrogen combustion may produce a little nitrous oxide (because there is nitrogen in air) there is no production of sulphur oxides or particulate matter. The other main product of hydrogen combustion is pure water. Carbon dioxide is not emitted from hydrogen, which makes it a great candidate fuel to meet the demands of the International Maritime Organization.

The IMO has mandated a 40% cut (based on 2008 numbers) in carbon dioxide emissions by 2030. That's only nine years and a few months away. The IMO is also demanding both that there be a 50% cut by 2050 and that the industry must be pursuing efforts towards a 70% cut.

There's a lot of work to be done and not much time to do it in.

Hydrogen is one of a few potential marine fuels that can simultaneously meet IMO standards, has enough energy to power a ship, and which can also be supplied in huge industrial volumes.

Greening hydrogen production

Typical hydrogen production is dirty, unfortunately. Hydrogen is normally produced from a fossil fuel feedstock, such as methane, which generates a lot of carbon dioxide. Walter Mérida, an Associate Dean of Research for Applied Science at the University of British Columbia, writes that grey hydrogen generates between nine and 12 kilograms of CO2 for each kilogram of hydrogen produced. That's not compatible with a worldwide push for lower carbon emissions.

Hydrogen production could be decarbonised if carbon capture and sequestration becomes economically viable. But that is complex, expensive and difficult at the moment.

Hydrogen can be made by splitting water using electricity. As each water molecule is comprised of two hydrogen atoms and one oxygen atom, splitting seawater produces two valuable industrial gases. There's plenty of seawater to use as a feedstock too. If hydrogen is made with renewably-sourced electricity from wind or solar then it's green as there's no production of carbon dioxide.

Hydrogen powered vessels

There are a few hydrogen-fuelled vessels. Hydrogen is used in a few tiny boats, some pleasure-craft, in experimental passenger ferries and even in a dual-fuel diesel-hydrogen submarine.

But there do not appear to be any hydrogen-fuelled ocean-going cargo ships. Of the 5,969 alternative-fuel-technology ships in operation, or on order, right now, just three vessels are hydrogen fuelled, according to class society DNV GL.

Cargo-carrying companies working Europe's inland river sector are experimenting with hydrogen fuel cells. French barge operator Compagnie Fluviale de Transport is building a compressed hydrogen-powered cargo barge at a shipyard in Romania. Funds for the project have been provided by the European Union's "Flagships" project.

In the Netherlands, the company Future Proof Shipping hopes to build a fleet of ten zero-emissions vessels for inland and short sea deployment. It has announced plans for an inland river container vessel (110 metres x 11.45 metres) to be retrofitted to run on hydrogen. The engine and gearbox will be replaced with electric motors, compressed hydrogen tanks, fuel cells and a battery. The new system will use cargo space equivalent to at least two forty foot containers. That's a costly trade-off. Ocean freight rates were generally about US$1,400 per forty-foot box on the China to North Europe route before the current freight rate boom, according to Freightos.

So, while the loss of space for two forty foot boxes doesn't sound significant, it's a big chunk of change over a 20-year vessel lifespan, especially if every ship in a fleet loses two forty-foot slots.

In Singapore, engineer Sembcorp Marine, oil major Shell and ship operator Penguin International will jointly develop a hydrogen-fuelled ship. Sembcorp will design, build and install a hydrogen fuel system on a ro-ro vessel; Shell will supply the fuel and charter the ship while Penguin will own and operate the vessel.

"This trial is an important step in demonstrating the applicability of hydrogen and fuel cells on ships… We see fuel cells and hydrogen as a promising pathway for decarbonising shipping and working with partners in this way will develop our understanding of this critical technology," said Nick Potter, General Manager of Shell Shipping and Maritime, Asia Pacific and Middle East.

Hydrogen carriers

An experimental ship has been built to trial the carriage of hydrogen as a cargo. The Susio Frontier is being developed by a consortium of Japanese heavy industrial manufacturers. The consortium is exploring technologies for a hydrogen supply chain using hydrogen sourced from Australian brown coal. The Susio Frontier, with dimensions of 116m x 19m, a draught of 4.5 m and 8,000 gross tons, will sail the 9,000km distance between Hastings, Victoria, to a liquefied receiving terminal at Kobe, Japan.

Western Australia-headquartered Global Energy Ventures (ASX: GEV) has also begun the development of a pilot-scale compressed hydrogen cargo ship.

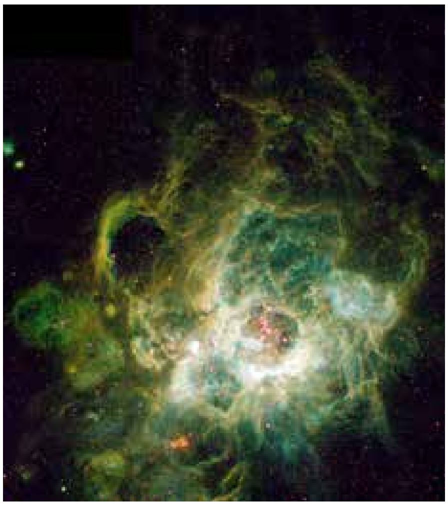
The company hopes to develop an operating fleet of hydrogen carriers by the mid-2020's and the development program is targeting full class approvals late in 2022. The 430 tonne capacity ship will be a scaled version of a 2,000-tonne compressed hydrogen ship, which received class society approval in principle in March 2021. The containment system, which fits within a Handymax-sized vessel, is made up of two large circular 12m diameter tanks contained within the hull of the ship. The system will store ambient temperature hydrogen at an operating pressure of 250 bar.

Poor energy density

While hydrogen packs a lot of energy content by weight, it's also one of the least energy dense fuels by volume. Hydrogen gas has an anaemic energy content by volume of 12.79 megajoules per cubic metre. Liquefied hydrogen has a much denser content of 10,027 MJ / m3.

In comparison, gaseous methane has an energy density of 40.34 MJ / m3; liquefied and super-cooled methane (i.e. LNG) has a content of 23,612 MJ / m3. Conventional diesel has an energy content by volume of 38,243 MH / m3 while residual fuel oil has an energy content of 41,787 MJ / m3.

"On a volumetric basis, due to its lower volumetric energy density, liquid hydrogen may require four times more space than [Marine Gas Oil] or about two times more space than liquefied natural gas for an equivalent amount of carried energy," reports Class Society ABS.



Pictured: a vast cloud of hydrogen in the Triangulum Galaxy. Hydrogen is the most abundant material in the universe. Photo: NASA.

High tech handling and storage

Handling hydrogen requires high technology and a lot of expertise.

Marine fuel hydrogen will be stored either as a compressed gas or a super-cold liquid. Gaseous hydrogen will be stored in tanks made from advanced composite materials. Compressed hydrogen will be stored at pressures between 350 bar (5,000 pounds per square inch (psi)) and 700 bar (10,000 psi). The lower end of that pressure range is about the same kind of pressure that experienced on the sea floor at about 3.4 kilometres deep. The upper end of that pressure range is close to the pressure experienced at the bottom of the Middle America Trench in the Pacific waters off Mexico, which is nearly seven kilometres deep.

Hydrogen can be stored as a liquid at sea-level pressure. But, to do that, it has to be really cold. It liquefies at a chilly minus 253 degrees Celsius. That's not far off "absolute zero", which is a temperature of minus 273.15 degrees Celsius. That's the temperature at which it is so cold that atoms stop moving.

Hydrogen can also be cryo-compressed i.e. it is kept cold and under pressure, which decreases storage requirements.

Small size, big danger

Hydrogen presents a myriad of dangers. Its molecules are super-small and can diffuse into metals, which makes the material crack and fracture. Vulnerable ship infrastructure includes the interior of tanks, weldments, pipes, valves and nozzles, according to the ABS. Cryogenic hydrogen brings its own dangers including ice build up which may block ventilation. Super cold hydrogen can also induce oxygen condensation and its subsequent evaporation can create an "oxygen rich and potentially flammable gas concentration".

Hydrogen presents problems both as an asphyxiant and as a fire risk. As an odourless, colourless gas, workers are unlikely to notice a hydrogen leak. Although it is not toxic, hydrogen can displace oxygen and cause death by asphyxiation. Hydrogen is explosive when combined with even small volumes of air. It ignites easily and, when it burns, it burns hot and with a near-invisible flame.

Needless to say, handling a fuel with this kind of pressure, temperature and hazard-profile is challenging.

A fuel of the future

In evaluating hydrogen as a marine fuel, class society ABS notes that "the various challenges exhibited by hydrogen as marine fuel must be resolved before being commercially available for use by a widespread fleet. Hydrogen is in the early stages of development for marine propulsion".

Hydrogen holds a lot of promise as it can be cleanly produced and burnt. It's also available in potentially huge volumes. But it's definitely a fuel of the future. There are formidable engineering issues but hardly any lived, operational, experience. And we haven't even touched on important matters such as cost or infrastructure.

Hydrogen may be a contender as a widely-used marine fuel in the future. But it's not a contender now.

It's not ready, basically.